PIP-II Beam Transfer Line Quadrupoles

V. Kashikhin, July 11, 2018

There needed 49 quadrupoles with the effective length of 0.2 m, integrated gradient 2 T, the magnet aperture 52 mm, good field region 24 mm, field non-linearity in the good field region 0.1%, and maximum current 13 A.

There were investigated number of variants including indirect and direct water cooling. These magnet parameters presented in Table 1.

easiest to fabricate

Name	Units	Indirect water cooling, 13A	Direct water cooling, 50A	Direct water cooling, 100A
Pole tip radius	mm	26	26	26
Integrated gradient	T	2	2	2
Center field gradient	T/m	10	10	10
Pole tip field	T	0.26	0.26	0.26
Coil ampere-turns/pole	A	2800	2800	2800
Coil peak current	A	13	50	100
Coil copper conductor	mm	2.6x2.6 (AWG10)	7x7, dia. 5	7x7, dia 5
Coil number of turns		210	54	28
Yoke length	mm	200	200	200
Winding resistance	Ohm	1.25	0.088	0.045
Magnet voltage	V	16.3	4.42	4.46
Magnet power	W	212	221	446
Number cooling circuits		1	1	1
Cooling hole diameter	mm	5	5	5
Water pressure drop	MPa	0.1	0.1	0.1
Water temperature rise	C	2.2	6.2	8.8
Number magnets in string		14	14	14
Voltage for the string	V	228	62	62
Total string power	kW	3.0	3.1	6.2

make 4mm

14 magnets

Results of preliminary 3D magnetic field analysis shown in Fig. 1 – Fig. 2. Fig. 1 shows that the iron yoke is not saturated. Fig. 2 shows longitudinal field distribution at the reference radius of 12 mm for 0, 30 deg., 45 deg. angles.

Talk to TJ about cost on Tuesday

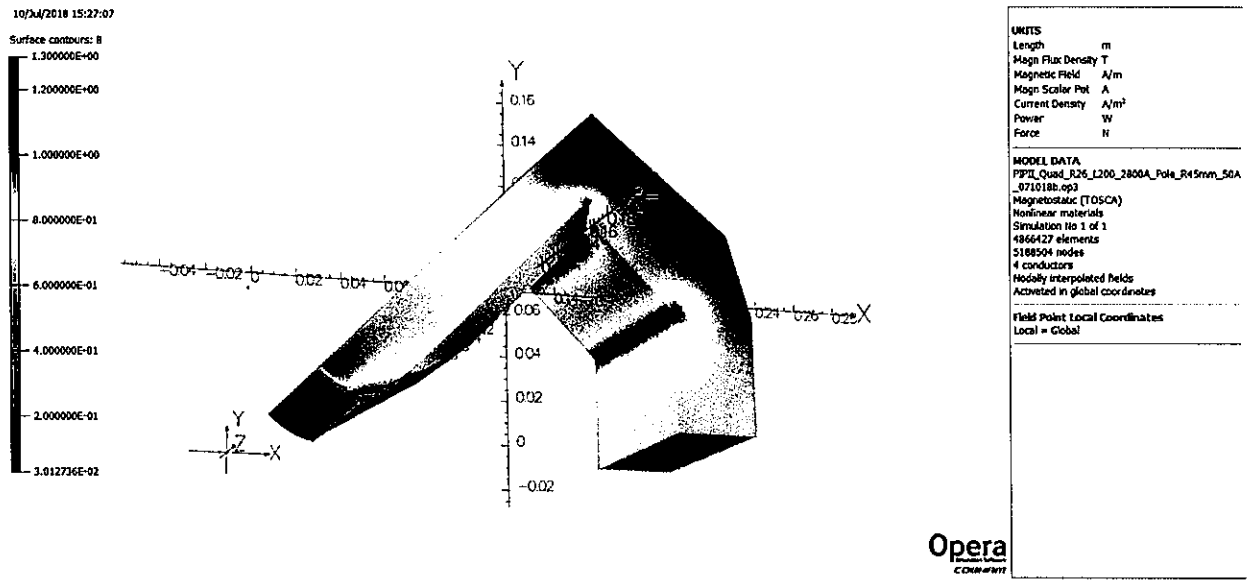

Fig. 1. Flux density in the magnet iron yoke.

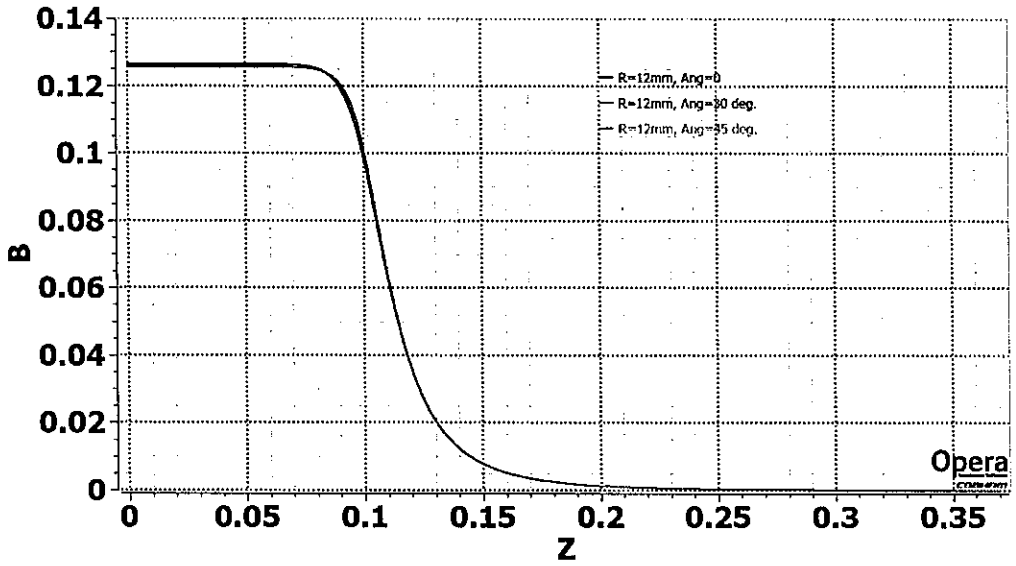

Fig. 2. B-field along Z-axis.

The integrated field non-linearity for this variant is less than the specified 0.1 % value for the reference radius 12 mm.

Fig. 3 – Fig. 5 shows the preliminary magnet cross-sections for all three variants.

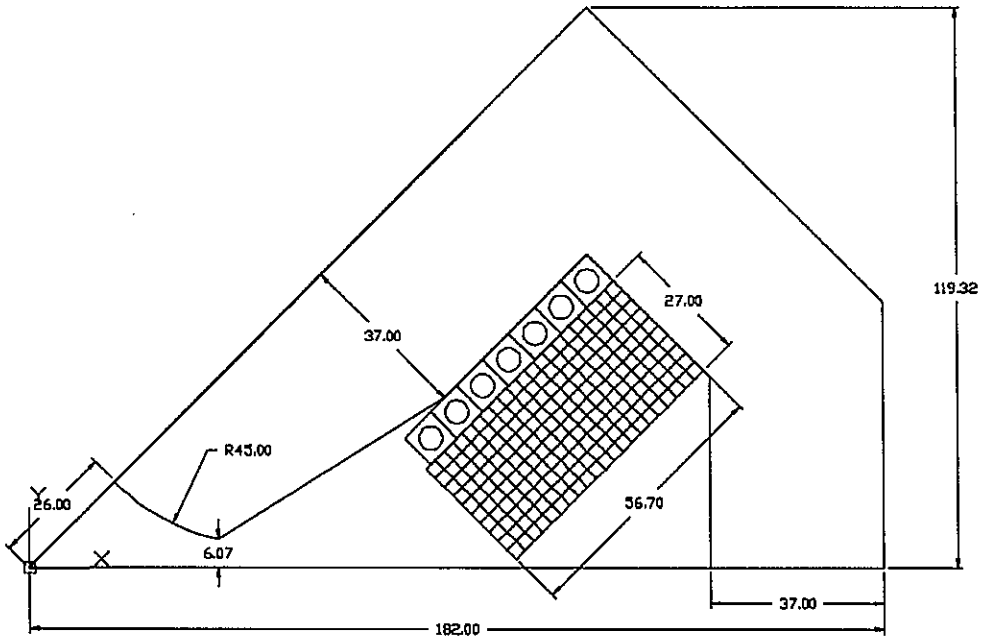

Fig. 3. Quadrupole with indirect water cooling and current 13 A.

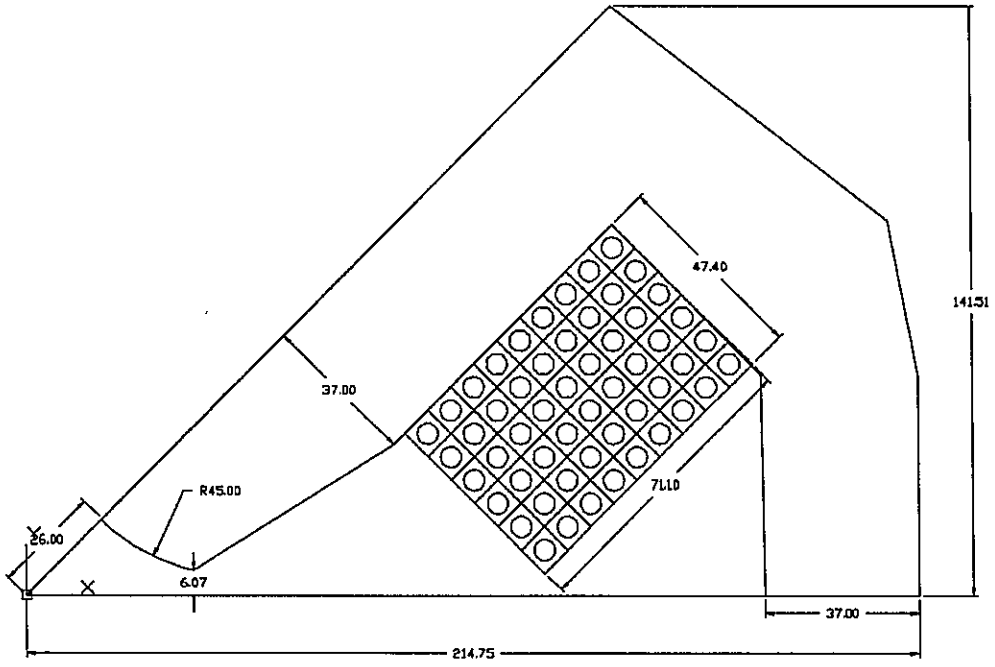

Fig. 4. Quadrupole with direct water cooling and current 50 A.

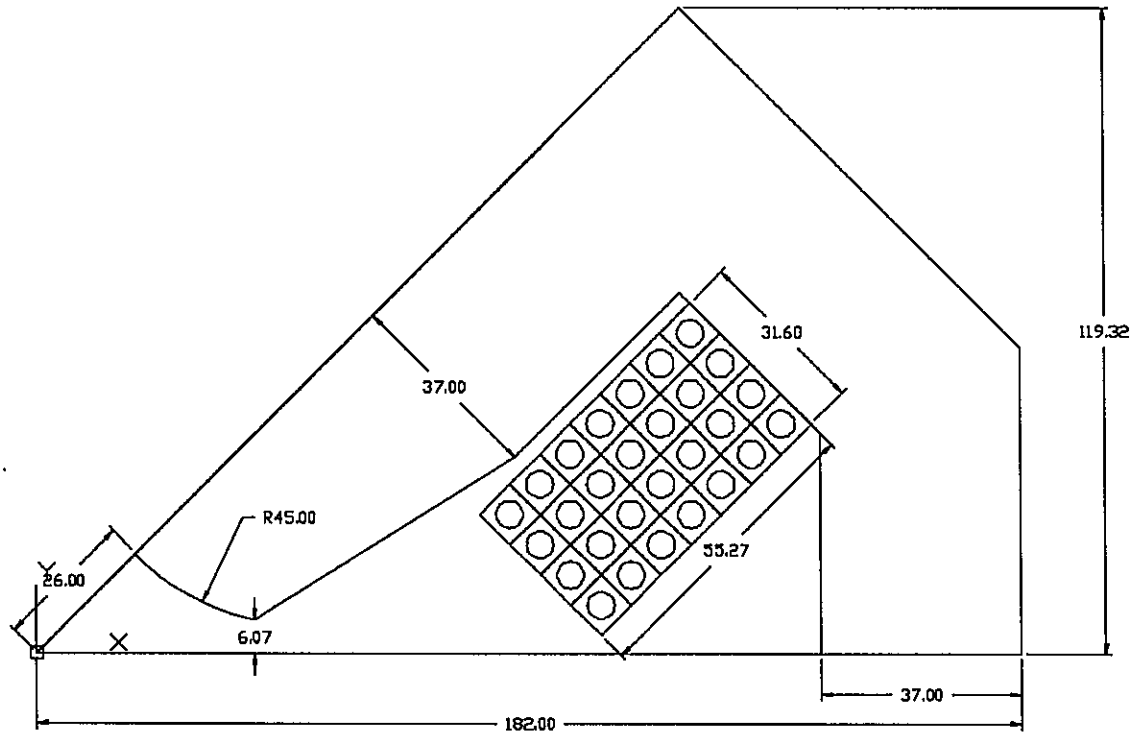

Fig. 5. Quadrupole with direct water cooling and current 100 A.

Summary

It is possible to design and fabricate any of these three magnet variants. But the direct water cooling design is more straightforward for the fabrication, and provides more reliable, stable cooling. The cost of power supply is proportional to the power, and not depend on current and voltage. Because string of magnets is connected in series, the cabling is not an issue. Besides there are 6 end of line quadrupoles with 3 T integrated gradients which will need even more cooling capacity. The preliminary analysis showed that these quadrupoles could be identical to direct water cooling magnets, because there is some margin in the iron flux density, and cooling. But these magnets will need 50% more current to obtain 50% larger integrated gradient at the same length. Even more compact water cooled magnets with lower current could be designed if reduce the conductor cooling hole diameter from 5 mm to 4 mm.